PB85-232270

Pressure Drop Reduction by Electrical Enhancement of Fabric Filtration

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Jul 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-232270

EPA/600/D-85/141
July 1985

PRESSURE DROP REDUCTION BY ELECTRICAL ENHANCEMENT OF FABRIC FILTRATION

by

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-85/141		PB85 232707/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Pressure Drop Reduction by Electrical Enhancement of Fabric Filtration	July 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Louis S. Hovis, Norman Plaks, and Bobby E. Daniel	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
See Block 12.	
	11. CONTRACT/GRANT NO.
	NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Air and Energy Engineering Research Laboratory Research Triangle Park, NC 27711	Published Paper: April 1985
	14. SPONSORING AGENCY CODE
	EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is Louis S. Hovis, Mail Drop 61, 919/541-3374.

16. ABSTRACT The paper discusses economic studies of electrostatic augmentation of fabric filtration (ESFF) that indicate that the reduced rate of pressure drop rise can lead to lower capital and operating costs. (ESFF has been evaluated in the laboratory and at various pilot scales over the past several years: results of the experimental studies have always shown that electrical enhancement substantially reduced the rate of pressure drop increase during the filtration cycle.) The mechanism by which ESFF operates has been investigated, and the primary collection enhancement methods have been verified. Application of ESFF to spray dryer byproduct shows promise of an even lower pressure drop than when filtering straight fly ash. A potential drawback to ESFF appears to be the requirement for special bags in reverse-air application. Woven-in electrodes of fine wires increase the cost and perceived fragility of the bags. A new center-wire electrode ESFF has been tested in the laboratory. The center electrode has a potential for even lower pressure drop, and the system has an added advantage: standard reverse-air bags can be used.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B 05C
Particles	Stationary Sources	14G
Gas Filters	Particulate	13K
Fabrics	Fabric Filters	11E
Filtration	Center-wire Electrodes	07D
Electrostatics	Electrostatic-enhancement of Fabric Filters	20C
Economic Analysis		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	19
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

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Electrostatic augmentation of fabric filtration (ESFF) has been evaluated in the laboratory and at various pilot scales over the past several years. Results of the experimental studies have always shown that electrical enhancement substantially reduced the rate of pressure drop increase during the filtration cycle. Economic studies of ESFF indicate that the reduced rate of pressure drop rise can lead to lower capital and operating costs. The mechanism by which ESFF operates has been investigated, and the primary collection enhancement methods have been verified. Application of ESFF to spray dryer byproduct shows promise of an even lower pressure drop than when filtering straight fly ash. A potential drawback to ESFF appears to be the requirement for special bags in reverse-air application. Woven-in electrodes of fine wires increase the cost of bags and the perceived fragility of the bags. A new center-wire electrode ESFF has been tested in the laboratory. The center electrode has a potential for even lower pressure drop, and the system has the added advantage that standard reverse-air bags can be used.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

The use of fabric filters to remove particles from gas streams is a well established industrial practice. It is currently a cost-effective particulate control technique for many coal-fired boiler operations.

Electrostatic fabric filtration (ESFF) differs from conventional fabric filtration in that an electrostatic field is applied at the fabric/dirty gas interface. For reverse-air applications ESFF can be achieved by applying a voltage across very fine stainless steel woven into the cloth in the warp direction or with external electrodes. In pulse-jet fabric filtration, the bag support cage can be properly insulated and electrified for use as the vertical electrodes.

The residual and operating pressure drops are reduced substantially with no apparent loss in collection efficiency. Previous laboratory and pilot-scale studies have consistently demonstrated this reduced pressure drop effect. The original concept of ESFF was developed by Lamb and Costanza.[1] The U.S. Environmental Protection Agency has continued to sponsor research to refine the original development and to determine commercial feasibility.

The Agency has supported work at both the laboratory and pilot scales. Laboratory experiments at Textile Research Institute (TRI), at Research Triangle Institute (RTI), and in-house at EPA's Air and Energy Engineering Research Laboratory have aided the understanding of the fundamental mechanisms of ESFF. Pilot studies of pulse-jet and reverse-air ESFF on an industrial boiler proved that the enhancement seen in the laboratory could be transferred to real plant conditions.

A pilot unit at Southwestern Public Service's (SPS) Harrington Station which utilized full-scale bags demonstrated that ESFF gave similar reduced pressure drops as had been observed in the laboratory and at the industrial pilot unit. Recent in-house experiments have applied the ESFF design to particulate matter from spray dryer operations for the control of SO_2.

Results and conclusions drawn from these tests are incorporated in this paper along with some new enhancement techniques which appear to make ESFF even more economically attractive.

ESFF PILOT PLANT STUDIES

Details of operation of the ESFF pilot plant at the DuPont site in Waynesboro, Virginia, are given in two EPA reports.[2,3] Parallel operation of electrified and control units was carried out on a slipstream from the boilers over a 2-year period in both pulse-jet and reverse-air cleaning modes. The electrode configuration changed during the course of the evaluation, but most of the results for pulse-jet operation were obtained using a standard felt bag over an electrified cage such as shown in Figure 1. An adaptation of the outside electrode harness was used for most reverse-air runs. An early version is shown in Figure 2. Typical results for the pulse-jet mode are shown in the pressure drop versus time plot (Figure 3). Both the residual pressure drop and the rate of increase of pressure drop are seen to be reduced by ESFF.

The cumbersome outside cage electrode arrangement for reverse-air was seen as a detriment to consideration of ESFF as a commercial option.

A task was undertaken to develop woven-in electrodes for reverse-air application before installation of ESFF in the larger pilot plant at SPS. The development of the woven-in electrode fabric is described in Reference 4. A combination of J.P. Stevens 648 Fiberglas fabric construction and Bekaert VN22/1X90 stainless steel yarn along with tedious weaving gave enough fabric for bags to be used in the SPS pilot plant. Photographs of the woven-in fabric are shown in Figure 4. The electrodes were placed on 2 cm centers so that an adequate electrical field of 4 to 5 kV/cm could be maintained at an applied voltage below corona onset. The fabric was made into bags by Menardi-Southern Corporation, and the bag construction is shown in Figure 5. A stainless steel braid was connected to every other electrode at opposite ends of the bag to give an alternating plus-minus pattern electrode polarity around the circumference of the bag.

The tests at SPS using 30-ft woven-in electrodes bags verified the enhancement effects of ESFF on a much larger scale than had been previously tested.[5] The average daily pressure drop variations with time shown in Figure 6 summarize the results of one test performed at SPS. At air-to-cloth ratios of 3 and 4, the average pressure drop across the control baghouse was approximately double that of the ESFF baghouse.

ESFF MECHANISMS

VanOsdell et al.[6] studied three ESFF mechanisms which have been proposed by various investigations of electrical enhancement. They examined in some detail the theory that particulate collection on the upstream low-density region of the filter was enhanced by electrostatics, the theory of non-uniform dust deposition on the filter surface because of coulomb forces, and the theory of dust cake porosity. After careful modeling each of the theories, the authors concluded that only the non-uniform deposition model will predict the pressure drop reduction that has been observed in ESFF. They tempered their conclusion by the fact that the deposition pattern of the first ESFF pulse-jet pilot unit appeared to be uniform. However, the EPA in-house experiments on spray dryer byproduct to be described below did display a non-uniform pattern, especially when a high grain loading or a high air-to-cloth ratio was used.[7]

EXPERIENCE WITH SPRAY DRYER SOLID BYPRODUCT

EPA's in-house application of ESFF to a spray dryer solid byproduct supplied by Joy Manufacturaing Company has shown that this material can benefit from electrical enhancement. The correlations of ESFF performance with temperature and electrical field and its dependence on electrical resistivity of dust have promoted basic understanding of the ESFF mechanism.

ESFF was not very effective when applied to spray dryer byproduct at fly ash operating temperatures and common fly ash grain loadings (Table 1). One reason appears to be the very high electrical resistivity of dry byproduct at 300°F (149°C). Increasing the moisture level to near actual operating conditions decreases the byproduct resistivity significantly. A combination of high moisture and temperatures in the range of 150° to 170°F (66° to 77°C) resulted in PDRs in the 0.15 to 0.2 range--well below the range typically observed even for fly ash. The PDR is a comparative measure of performance. It is the ratio of ΔP with power on to ΔP with power off, and the lower the PDR, the greater is the performance. This response to ESFF held up at the high grain loadings associated with spray dryer outlet conditions.

The extremely good response of spray dryer byproduct to ESFF is perhaps best illustrated by pressure drop comparisons taken directly from recorder charts. Figures 7 and 8 are reproduced from the pulse-jet recorder. Figure 7 shows two ΔP curves with power off followed by three curves with power on (ESFF). The first curve after a field has been applied to the electrodes is still under the influence of the conventional cycle which has just preceded turning power on. One pulse of compressed air has not been sufficient to completely clean the bag which, without the electric field, is uniformly covered with dust. Two pulses did clean sufficiently as shown by the almost complete recovery of the first ESFF curve in Figure 8.

A photograph of dust deposited on the bag under ESFF conditions, Figure 9, helps to explain why dust deposition with the electric field on gives a lower pressure drop buildup with time. As seen in Figure 9, dust deposition is along the electrodes. This accounts for the lower ΔP because a nearly clean fabric path between electrodes is provided which offers little resistance to gas flow. The highly non-uniform dust distribution results in a much lower pressure drop than a uniform distribution of the same quantity of dust. The non-uniform dust layer also proves easy to remove during cleaning, reducing the residual ΔP creep characteristics of most baghouse operations.

The ΔP curves for conventional filtration (power off) in Figures 7 and 8 are not reproducible or consistent. Experience with the pulse-jet unit indicated that, under this high grain loading, only a limited number of filtration cycles could be performed before the pressure drop curve would exceed the chart limit. This is a consequence of inadequate cleaning[8]; increasing the cleaning energy might have kept the ΔP on the chart. Under ESFF, however, these same cleaning pulses provided sufficient cleaning energy to give a stable reproducible ΔP plot. Because PDR is based on a comparison of ΔP's from ESFF and conventional baghouses, the PDR's reported herein are based only on the average of a limited number of conventional cycles.

Figure 10 is a reverse-air recorder chart comparison similar to the one for pulse-jet just reviewed. The PDR values are extremely good here also, being in the range of 0.2 to 0.3. Dust deposition along the electrodes is not readily observed because of the inside-the-bag nature of particulate collection filtration. However, there is no reason to think that the mechanism for achieving a low pressure drop differs from that of the pulse-jet case. The record of ΔP indicates that, for the cycling shown in Figure 10, there is sufficient cleaning energy to remove the uniform layer of dust under conventional filtration because the ΔP curve is reproducible. The pressure drop rose above the chart limit for the power-off condition only when the filtration cycle time was doubled.

The striking difference between the power-on and power-off curves of Figures 7 and 8 (pulse-jet) and Figure 10 (reverse-air) can be appreciated by comparing them with similar curves for fly ash (Figure 11, reverse-air). The ESFF effect, while clearly evident, is much less pronounced in the Figure 11 data which yield a PDR typically in the 0.4 to 0.6 range.

VERIFICATION OF ESFF MECHANISM

The non-uniform dust deposition pattern, alluded to in describing the lower ΔP, and the ease of cleaning were readily observed through the port on the pulse-jet baghouse. The non-uniform dust deposition pattern, which was emphasized by the large grain loading in the case of spray dryer byproduct, is most likely a consequence of relatively long range coulomb forces exerted on the dust.[9] Charged particles are attracted to either the positive or negative electrode with more depositing on the electrode of polarity opposite to the charge on the majority of particles. Other mechanisms[6,10] may play a role, but the non-uniform deposition clearly dominates. Figures 9 and 12 show the buildup of dust along the electrodes. That the dust can be adequately removed from the bag, as evidenced by a stable low value of residual ΔP, also contributes to the effectiveness of ESFF.

MAXIMIZING THE ESFF EFFECT

It has been concluded that the spray dryer byproduct, because of the conditions under which it is filtered, is a likely candidate for ESFF. Although the dust has a very high electrical resistivity when dry, a combination of low operating temperature and high moisture (normal conditions for spray dryer operation) lowers this resistivity into a favorable range for ESFF. Both high moisture and low temperature are necessary. Figure 13 shows a pulse-jet baghouse response to a reduction in filtration temperature versus a reduction in temperature with added moisture. The lower PDR response to temperature is measurable, but it takes the added moisture to observe the impressively low values of PDR. There is no intended implication that electric field is held constant in Figure 13. The Figure 13 data were collected at "maximum" allowable electric field--that value of electric field just below corona onset. This allowable value of electric field increases with increasing moisture and decreasing temperature. Thus, the low-temperature, high-moisture data of Figure 13 were collected under higher values of applied electric field than the low-moisture, high temperature data.

This field dependence is demonstrated for pulse-jet operation in Figure 14 and for reverse-air operation in Figure 15. It is interesting to note that an applied electrode voltage of approximately 11 kV (5.5 kV/cm) and approximately 4 kV (2 kV/cm field) for pulse-jet and reverse-air, respectively (at this temperature and moisture condition), gives an ESFF result comparable to SPS fly ash at 300°F (149°C) and low moisture. Data are not available to confirm this, but it is surmised that electrical resistivities are nearly the same for the two products at these conditions.

ECONOMICS

Several studies[2,3,4] have attempted to compare the cost of conventional and ESFF baghouses. The most important factors in establishing a cost difference is the initial cost of the bags and the life of the bags. In the case of pulse-jet, where no special bags are required and the cost of electrifying cages is offset by the fewer number of cages, it has been estimated that a saving of 50% in total annual cost is not inconceivable. A more conservative estimate of reverse-air filtration[4] puts ESFF and conventional equal in annual cost at an A/C of 4 (an unrealistic AC for conventional filtration) because of the higher bag cost for the ESFF. However, as stated in Reference 4, the most appropriate comparison should be made between the highest A/C that can be operated for the two systems because of pressure drop limitations. For example at an A/C of 4 for

ESFF and an A/C of 2 for conventional, the total annual saving is estimated at 32% for the ESFF system.

FUTURE WORK

ESFF for use in the reverse-air cleaning mode is encumbered with a higher bag cost and a perceived bag fragility because of the woven-in electrode fabric requirement. Recent experiments with a different electrical field concept hold promise of lower cost and increased effectiveness. This has been referred to as the center-wire ESFF. An electrical field is generated by a larger potential between the wire and an electrical ground at the bag surface. The entering particles are charged by the high voltage, unlike in conventional ESFF where non-uniform collection is dependent solely on weak natural charges. Preliminary results are extremely encouraging with PDR's in the 0.3 range. Tests at 200°F, or less, in which Menardi Southern's "No Shock" polyester knit bags could be used, the PDR's were even lower. The new ESFF method is to be installed in a pilot plant on a Navy site. The problem of grounding the bag surface will have to be dealt with.

CONCLUSIONS

Laboratory and pilot-scale investigations have shown that electrical enhancement of fabric filtration results in a reduced rate of pressure drop increase for fly ash and spray dryer byproduct. The lower pressure drop indicates a potential for higher gas velocity and lower capital and operating cost with electrical enhancement. A new center-wire electrode system shows promise of further improvement in performance and is being investigated.

METRIC CONVERSIONS

1 in. of H_2O = 249 Pa

1 grain/ft^3 = 2.29 g/m^3

1 ft/min = 0.5 cm/s

1 in. = 2.5 cm

1 ft = 0.3 m

(°F - 32)5/9 = °C

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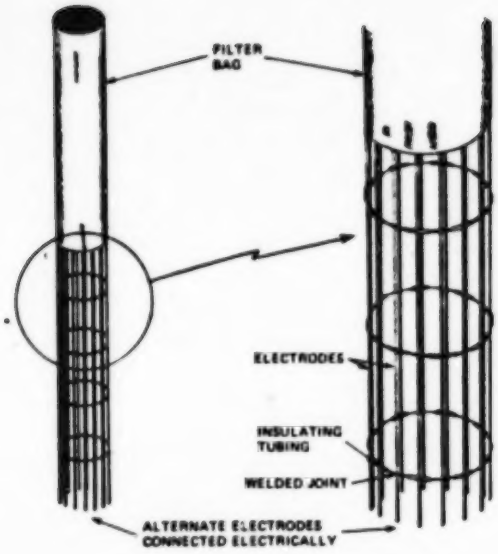

Figure 1. Inside electrodes utilizing insulating tubing on cage rings.

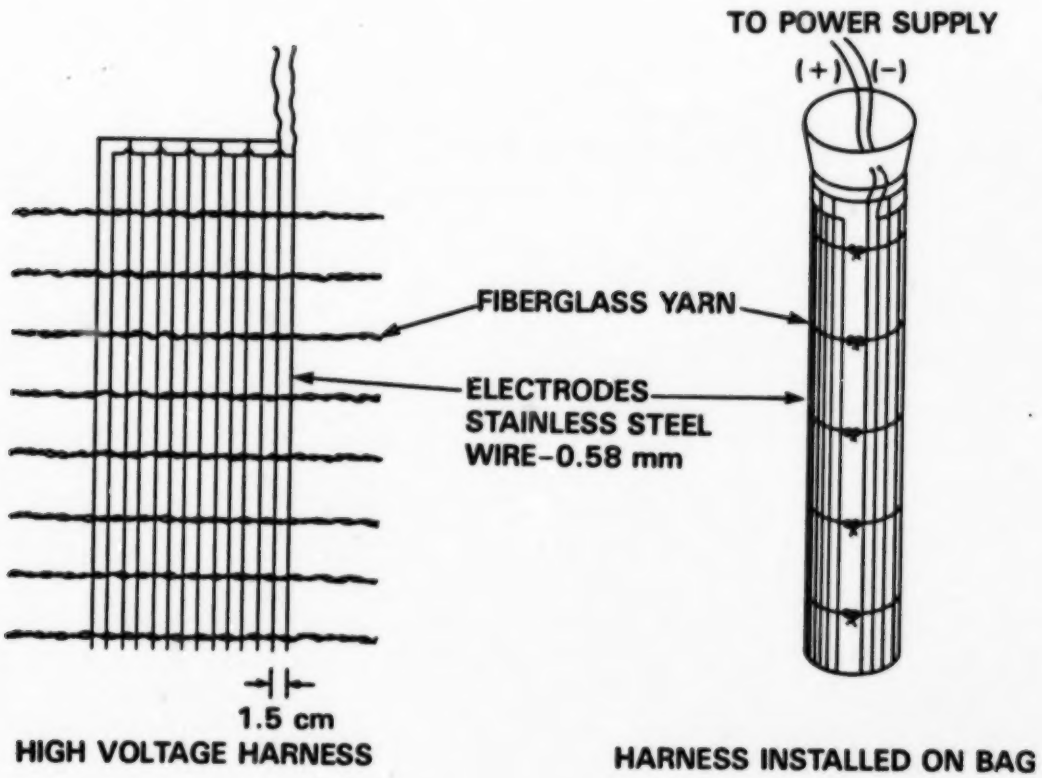

Figure 2. Harness for applying electric field parallel to the surface of a fabric filter bag.

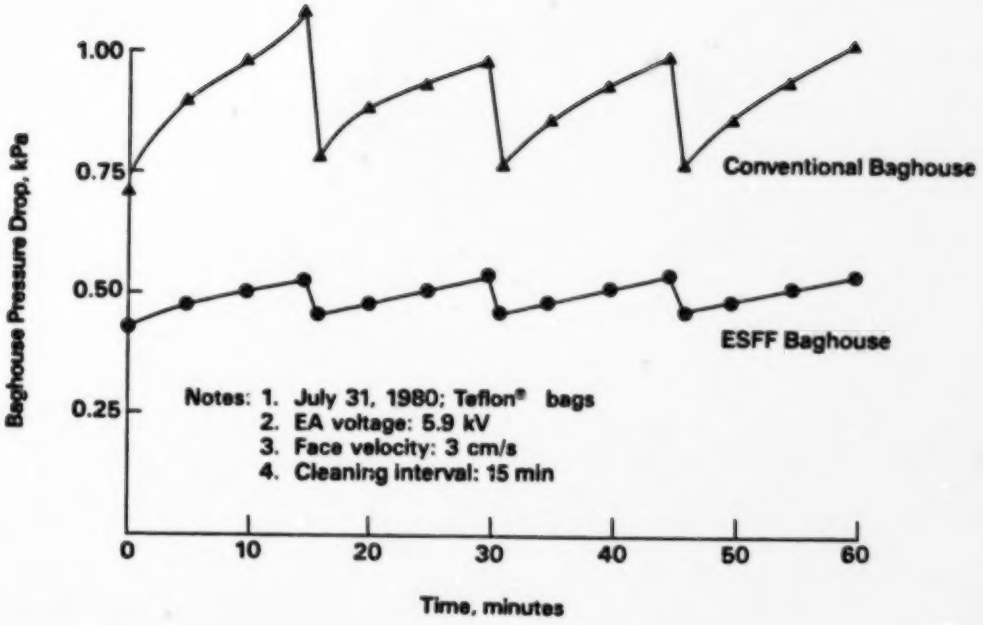

Figure 3. Pressure drop comparison for conventional and ESFF pilot pulse-jet baghouses.

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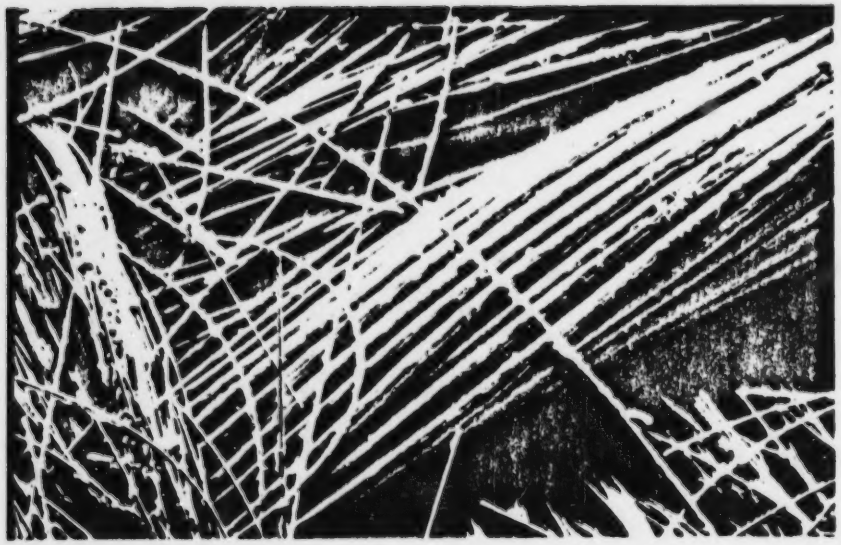

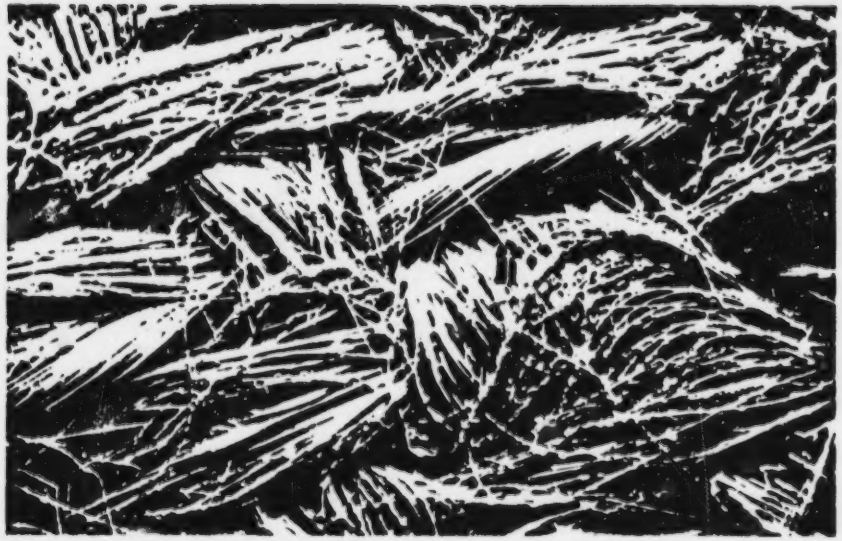

Magnification = 60X

Magnification = 15X

Figure 4. Woven-electrode fabric showing stainless steel fiber electrode.

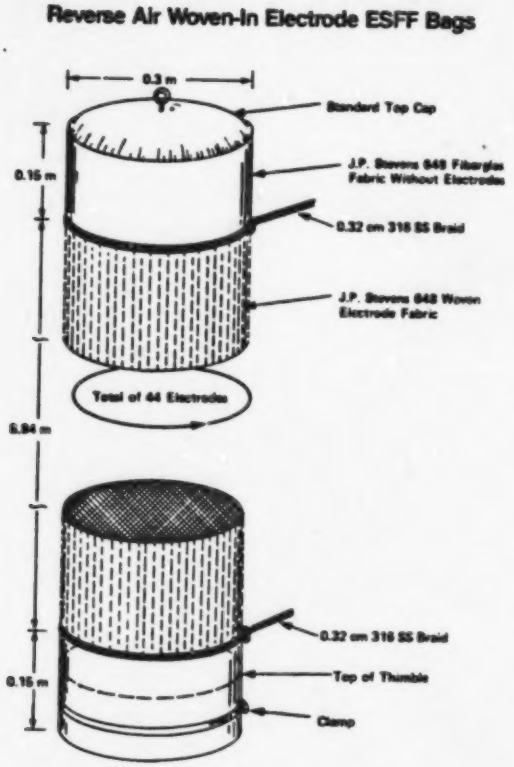

Figure 5. Construction of the woven-electrode bags.

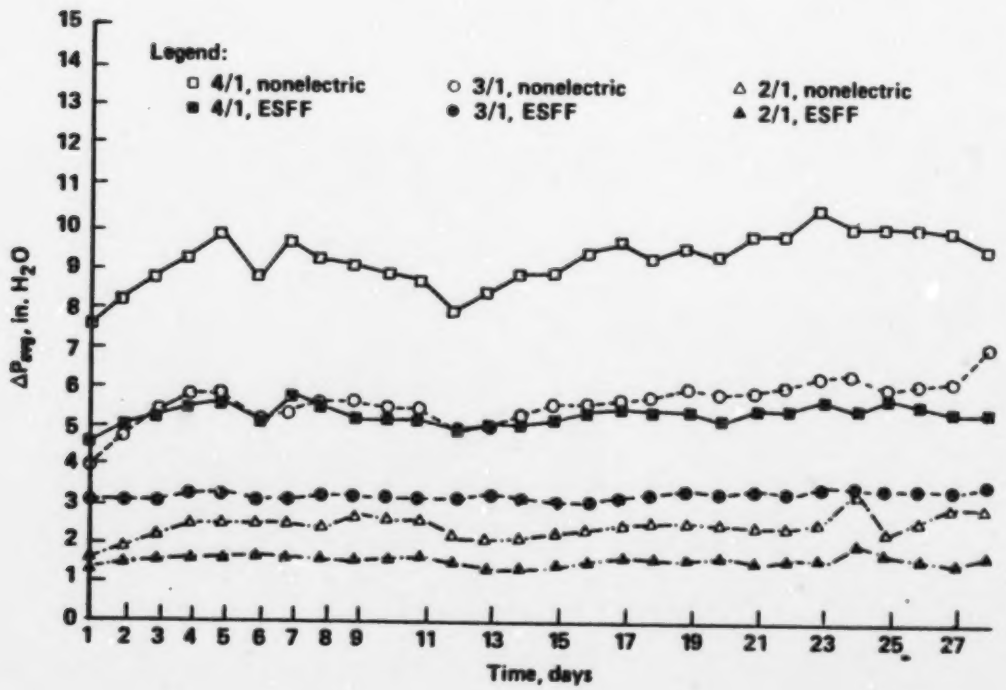

Figure 6. Daily average pressure drop versus time for cyclical tests at various air/cloth ratios.

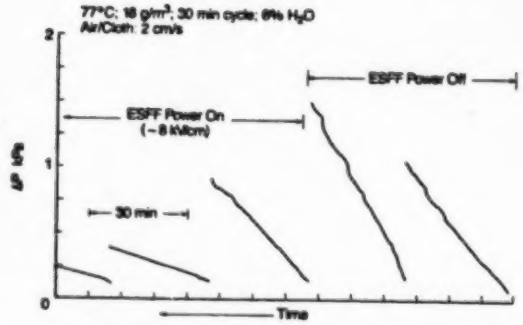

Figure 7. Change in ΔP brought about by turning the electric field on (pulse jet, spray dryer by-product).

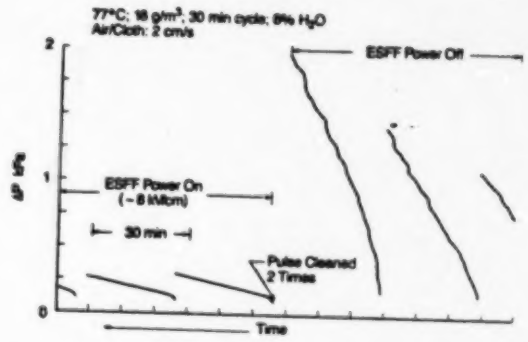

Figure 8. Change in ΔP brought about by turning the electric field on (pulse jet, spray dryer byproduct, with two cleaning pulses).

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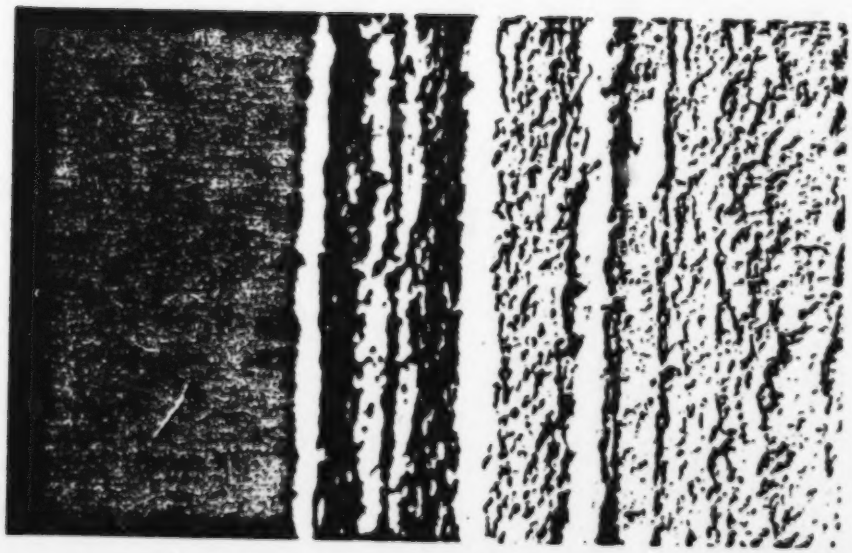

Figure 9. Spray dryer byproduct deposit on electrified bag (pulse jet cleaning).

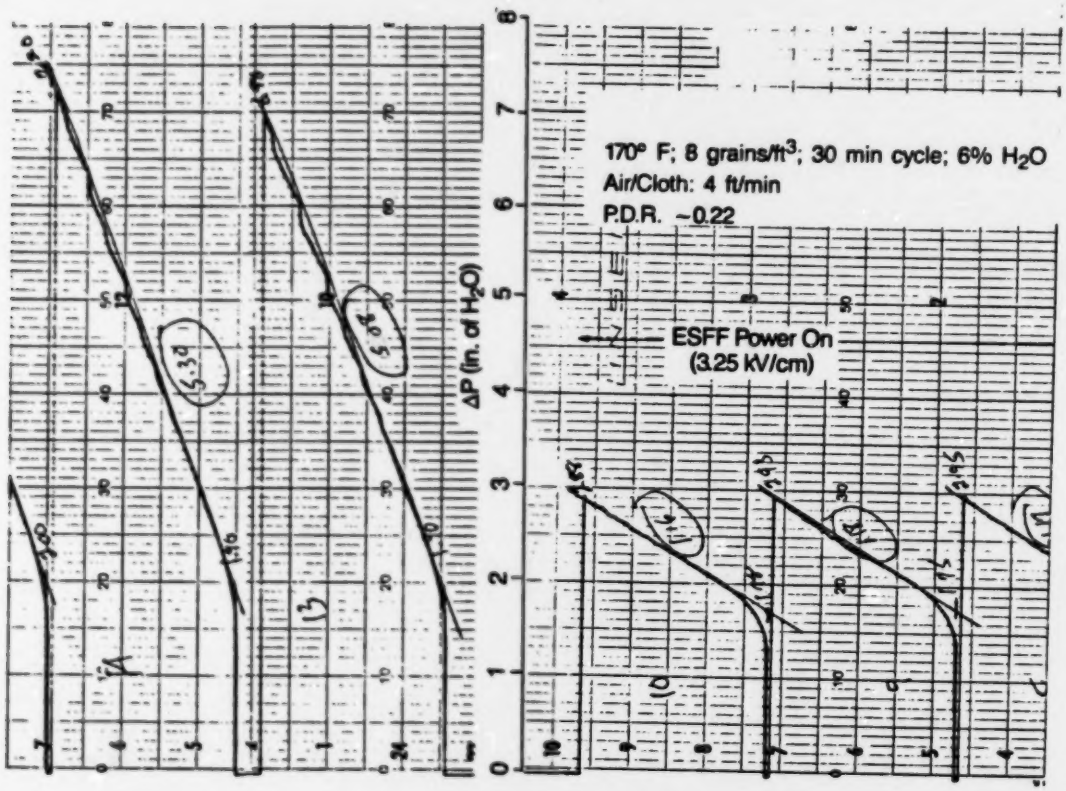

Figure 10. Electric field effect on spray dryer byproduct filtration (reverse air).

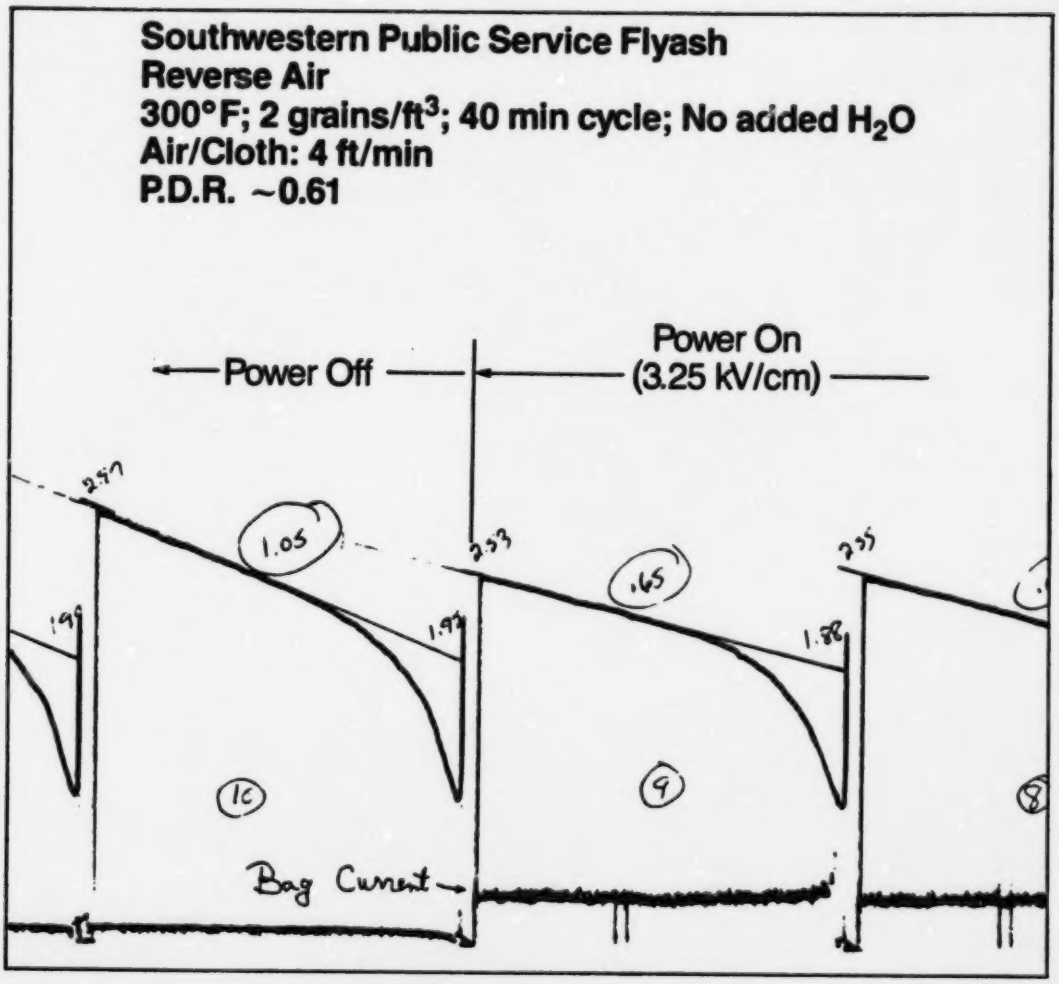

Figure 11. Electric field effect on SPS fly ash filtration.

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Figure 12. Spray dryer byproduct deposition pattern (pulse jet).

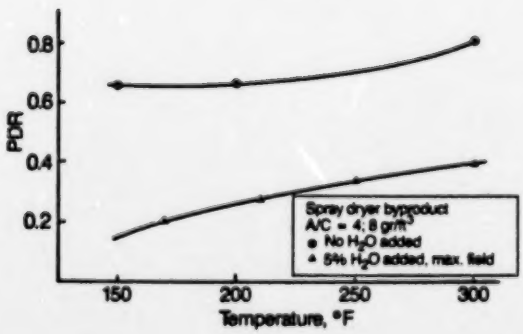

Figure 13. Pressure drop reduction attributable to reduced temperature and increased moisture (spray dryer byproduct, pulse jet).

TABLE 1. ESFF RESULTS: COMPARISON OF FLY ASH AND SPRAY DRYER BYPRODUCT

Baghouse	Dust Type	Water Added, %	Temperature, °F	Electric Field, kV/cm	Loading, grains/ft^3	Effect (PDR)
Pulse Jet	Fly ash	o	300	6	2.5	0.4-0.5
	Byproduct	0	300	6	2.5	1
	Byproduct	0	200	6.5	2.5	0.67
	Byproduct	6	300	7	2.5	0.4
	Byproduct	5	200	7.5	2.5	0.26
Reverse Air	Fly ash	0	300	2	2.5	0.5-0.6
	Byproduct	0	300	2	2.8	0.85
	Byproduct	0	200	2	2.8	0.74
	Byproduct	5	250	2	2.3	0.6
	Byproduct	5	200	2.5	2.3	0.29

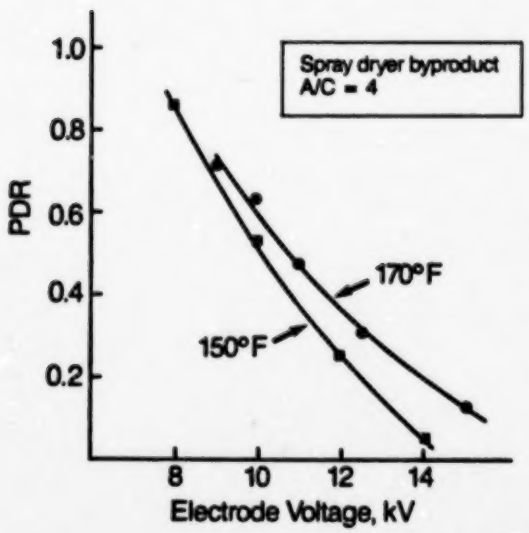

Figure 14. Field dependence of pressure drop reduction (spray dryer byproduct, pulse jet).

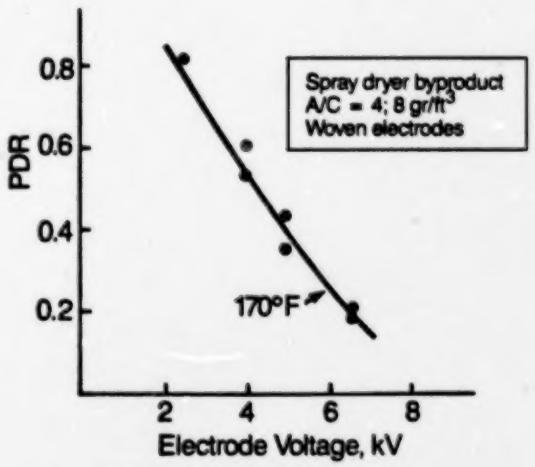

Figure 15. Field dependence of pressure drop reduction (spray dryer byproduct, reverse air).